How We Experience Being Alone: Age Differences in Affective and Biological Correlates of Momentary Solitude

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Abstract: Background: Spending time alone constitutes a ubiquitous part of our everyday lives. As we get older, alone time increases. Less is known, however, about age differences in the experience of spending time alone (momentary solitude). Objectives: We examined time-varying associations between momentary solitude, affect quality, and two hypothalamic-pituitary-adrenal axis activity markers [salivary cortisol; dehydroepiandrosterone sulfate (DHEAs)] to better understand the affective and biological correlates of momentary solitude across the adult life span. Method: A total of 185 adults aged 20-81 years (mean age = 49 years, 51% female, 74% Caucasian) completed questionnaires on momentary solitude (alone vs. not alone) and current affect on a handheld device, and provided concurrent saliva samples up to seven times a day for 10 consecutive days. Data were analyzed using multilevel models, controlling for the overall amount of time participants spent alone during the study (overall solitude). Results: Greater overall solitude was associated with decreased average high arousal positive affect and increased average cortisol and DHEAs levels. Momentary solitude was associated with reduced high arousal positive affect, increased low arousal positive affect, and increased low arousal negative affect. Age by momentary solitude interactions indicate that greater age was associated with increased high arousal positive affect and reduced low arousal negative affect during momentary solitude. Furthermore, momentary solitude was associated with increased cortisol and DHEAs. With greater age, the association between momentary solitude and cortisol weakened. Conclusion: Consistent with the negative connotations to loneliness and objective social isolation, greater overall solitude was associated with negative affective and biological correlates. Spending a large overall amount of time alone in old age might thus have negative ramifications for health and well-being. Momentary solitude, in contrast, can be a double-edged sword as evidenced by both positive and negative well-being implications. Importantly, greater age is linked to more favorable affective and biological correlates of momentary solitude. The momentary state of spending time alone is thus an experience that is not necessarily negative and that may improve with aging.

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How We Experience Being Alone: Age Differences in Affective and Biological Correlates of Momentary Solitude

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Key Words
Solitude · Affect · Cortisol · Dehydroepiandrosterone sulfate · Age differences · Time sampling

Abstract
Background: Spending time alone constitutes a ubiquitous part of our everyday lives. As we get older, alone time increases. Less is known, however, about age differences in the experience of spending time alone (momentary solitude). ***Objectives:*** We examined time-varying associations between momentary solitude, affect quality, and two hypothalamic-pituitary-adrenal axis activity markers [salivary cortisol; dehydroepiandrosterone sulfate (DHEAs)] to better understand the affective and biological correlates of momentary solitude across the adult life span. ***Method:*** A total of 185 adults aged 20–81 years (mean age = 49 years, 51% female, 74% Caucasian) completed questionnaires on momentary solitude (alone vs. not alone) and current affect on a handheld device, and provided concurrent saliva samples up to seven times a day for 10 consecutive days. Data were analyzed using multilevel models, controlling for the overall amount of time participants spent alone during the study (overall solitude). ***Results:*** Greater overall solitude was associated with decreased average high arousal positive affect and increased average cortisol and DHEAs levels. Momentary solitude was associated with reduced high arousal positive affect, increased low arousal positive affect, and increased low arousal negative affect. Age by momentary solitude interactions indicate that greater age was associated with increased high arousal positive affect and reduced low arousal negative affect during momentary solitude. Furthermore, momentary solitude was associated with increased cortisol and DHEAs. With greater age, the association between momentary solitude and cortisol weakened. ***Conclusion:*** Consistent with the negative connotations to loneliness and objective social isolation, greater overall solitude was associated with negative affective and biological correlates. Spending a large overall amount of time alone in old age might thus have negative ramifications for health and well-being. Momentary solitude, in contrast, can be a double-edged sword as evidenced by both positive and negative well-being implications. Importantly, greater age is linked to more favorable affective and biological correlates of momentary solitude. The momentary state of spending time alone is thus an experience that is not necessarily negative and that may improve with aging.

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Introduction

Most people spend a substantial amount of their time alone, particularly in old age [1]. Momentary solitude is characterized by the absence of any social interaction [2], and it can be operationally defined as 'the objective condition of being alone' [1, p. 157] at a certain moment in time. Interestingly, momentary solitude can be a double-edged sword. On one hand, momentary solitude offers opportunities for emotional renewal, relaxation, and self-reflection [3]. On the other hand, momentary solitude can also have negative ramifications such as feelings of loneliness, especially when it occurs involuntarily [4, 5]. The negative correlates of momentary solitude are relatively well studied [6], whereas research on potential positive correlates is scarce. The current study aims to better understand the positive and negative correlates of momentary solitude as individuals engage in their typical everyday life routines and environments. Specifically, we examine within-person fluctuations in momentary solitude with self-reported affect and with two indicators of hypothalamic-pituitary-adrenal (HPA) axis activity, salivary cortisol and dehydroepiandrosterone sulfate (DHEAs), using up to 50 repeated daily life assessments from a life span sample (n = 185; age range = 20–81 years).

One of social psychology's basic tenets is that humans have an inherent need to belong and to engage in social interaction [7]. Most previous research thus concentrates on the positive effects of social interaction and the negative effects of a lack of social interaction [8, 9]. For instance, a large literature focuses on loneliness. Loneliness is a negative subjective state that stems from a 'discrepancy between one's desired and achieved levels of social relations' [10, p. 32]. As such, the concept of loneliness is distinct from momentary solitude (the objective state of being alone) and overall solitude (the overall amount of time a person spends alone).

In line with the idea that a lack of social interaction is harmful, loneliness has been associated with various mental and physical health issues [6]. Higher overall solitude, which is conceptually similar to and will thus be used as a proxy for objective social isolation (i.e. social disconnectedness), has also been associated with clear negative outcomes, such as higher depression, lower life satisfaction, increased cardiovascular disease risk, and higher mortality [8, 11, 12]. Given the large literature on the negative connotations of loneliness and social isolation, the possibility that momentary solitude might have benefits is often neglected. This literature gap is unfortunate, because emerging research shows that there are benefits specific to momentary solitude, such as freedom from social restrictions and demands [13], emotional renewal [3], creativity [14], improved concentration [3], and increased sense of control [5]. To summarize, the objective state of being alone (momentary solitude) is conceptually distinct from persistent social isolation or subjective perceptions of loneliness and, in contrast to social isolation and loneliness, has been associated with both pitfalls and a broad spectrum of potential benefits.

Solitude, Affect, and Age

What do we know about the everyday correlates and consequences of momentary solitude as individuals engage in their daily life routines and environments? A number of studies have used repeated daily life assessments ('time sampling') to examine time-varying associations between momentary solitude and affective states [3, 5, 15]. Findings suggest that individuals report less positive and more negative affect when alone as compared to when in the presence of other people [4, 13]. For example, momentary solitude has been associated with less favorable affect on bipolar scales (e.g. happy/sad, cheerful/irritable) in adolescents, young adults, and middle-aged adults [3]. Momentary solitude has also been linked to less positive affect but not to more negative affect in the oldest-old (participants aged 84–102; [15]). Such findings are in line with the idea that affective experiences during solitude may differ across the adult life span and that momentary solitude might be experienced more favorably in old age.

Why might greater age be associated with more favorable solitude experiences? Community-dwelling older adults often report more positive affective well-being than middle-aged and young adults, which is attributable at least in part to their superior emotion regulation skills [16, 17]. In line with this notion, Larson [1] has shown that older adults report less loneliness during solitude than young adults. We therefore propose that greater age will be associated with more positive and less negative affect during momentary solitude.

Solitude, HPA Axis Activity, and Age

In addition to affective correlates, momentary solitude has been linked to biological stress indices [13, 18, 19]. The current study specifically targets two prominent indicators of HPA axis activity: cortisol and DHEAs. Cortisol and DHEAs have unique circadian rhythms, with overall high levels in the morning and a subsequent decrease over the course of the day, and they play an integral role in orchestrating the body's response to stress [20, 21].

Chronically elevated cortisol has been associated with increased physical and mental health risks [22]. DHEAs plays a protective role in buffering the negative effects of increased cortisol on physical and mental health [23]. Previous research linking momentary solitude with within-person fluctuations in cortisol indicates that being alone is associated with increased salivary cortisol levels in adolescents [18], college students [13], and middle-aged women but not men [19]. To our knowledge, no research has investigated links between momentary solitude and DHEAs levels.

Why would we expect age differences in associations between momentary solitude and cortisol and DHEAs? Cortisol levels increase with age, possibly reflecting wear and tear in biological stress systems including the HPA axis [24, 25]. In contrast, DHEAs peaks in early adulthood and then declines with age [26]. Despite their increased biological vulnerability, older adults do not show increased HPA responses to commonly used acute psychosocial stressors in the lab as compared to young adults [27, 28]. This finding is consistent with propositions from the model of strength and vulnerability integration (SAVI) [29], which posits that older adults' improved coping and emotion regulation skills might help ward off stress responses. SAVI further postulates that older adults might not respond to situations that elicit low levels of arousal due to their decreased biological flexibility. Taking the aforementioned into account, greater age is expected to be related to weaker positive relationships between momentary solitude and both momentary cortisol and DHEAs.

The Current Study

The current study aimed to thoroughly investigate dynamic associations between momentary solitude, affect, and markers of HPA axis activity, as well as age differences therein, using up to five repeated daily life assessments ('time sampling') each day over a period of 10 consecutive days from a sample of 185 adults aged 20–81 years [see 24, 30]. Affect items were chosen to capture differences in both valence and arousal, allowing for the possibility that solitude-affect associations might be more visible with regard to low arousal affective states [3, 13]. We hypothesized that momentary solitude would be associated with reduced momentary positive affect (high arousal positive affect, low arousal positive affect) and increased momentary negative affect (high arousal negative affect, low arousal negative affect). We further expected momentary solitude-affect associations to be weaker with greater age. With respect to biological correlates, we hypothesized that momentary solitude would be related to increased momentary cortisol and DHEAs. Age was expected to moderate these within-person associations in such a way that greater age would be related to less pronounced solitude-cortisol relationships and less pronounced solitude-DHEAs relationships. All models controlled for overall solitude across the study period, gender, and a number of other factors that have been shown to be associated with cortisol and DHEAs in previous research, including body mass index (BMI), exercise, caffeine intake, smoking, and alcohol and medication/drug use [31].

Methods

Participants

Approximately equal numbers of young, middle-aged, and older adults were recruited from the Atlanta metropolitan area through an existing research database, mailed out postcards, media advertisements, and participant referral to participate in a study on everyday problem solving and emotion regulation across the life span. Out of 777 participants who called requesting study information, 246 (32%) entered the study. Study exclusion criteria were circumstances and conditions known to impact HPA axis functioning, including pregnancy, breastfeeding, thyroid dysfunction, mental disorders such as PTSD, bipolar disorder, psychosis, eating disorders, and alcohol/substance abuse, neurodegenerative disorders, adrenal disorders, hormone-producing cancers, shift work, and obesity (BMI >35). After entering the study, 40 participants dropped out predominantly due to time limitations. Six participants were discontinued, and data from 15 participants were excluded due to taking psychotropic medication, suffering from mood or anxiety disorders, experiencing unusual events (such as death in the family, surgery, or only working on 3 out of 7 business days), misunderstanding the study material, missing too much data, or having unreliable data from saliva samples. The final sample was composed of 185 adults with a mean age of 48.5 years (SD = 19.2, range: 20.0–80.9). Fifty-one percent of the sample was female, 23% were college students, and 64% had a college degree. Most participants (74%) were Caucasian and 18% were African-American. Participants who completed all parts of the study were compensated USD 100. The study was ethics approved by the Georgia Institute of Technology Institutional Review Board. See Scott et al. [30] for more details about the study sample and procedures.

Procedure

Participants completed a mail-out package including background information and social and personality variables prior to the study. Then, participants started a 10-day time sampling phase during which they completed questionnaires on portable electronic devices (Palm Pilot Tungsten T2) and provided concurrent saliva samples seven times a day. The first two daily collection points were self-initiated at waking and 30 min later and included questions on factors influencing the interpretation of saliva assays. The other five assessments were beep-prompted at quasi-random times

approximately every 3 h – with the latest possible prompt at 9:30 p.m. – and included information about participants' momentary solitude, current affect, and control variables. After the 10-day phase, participants returned their equipment and provided study feedback. Participants reported that the study period was typical of their everyday lives (mean = 4.2, SD = 1.0, on a 5-point scale). Out of 50 beep-prompted questionnaires, participants answered 46.8 on average (93.6%, SD = 3.3), demonstrating excellent compliance.

Measures

Momentary Solitude

Momentary solitude was operationally defined by participants' account of their social situation at the time of each beep. Participants indicated five times a day whether they were currently alone or with other people by answering the question 'Who are you with?' (coded as 0 = not alone, 1 = alone). Participants were instructed to report who they were with if another person was physically present and also if they were communicating with someone electronically. Individuals engaged in electronic interaction were considered to be not alone as solitude is characterized by separation from social communication [1]. All participants reported being alone at least once over the study period.

Momentary Positive and Negative Affect

Participants also reported their current affective state by rating the extent to which they felt happy, sad, calm, sleepy, nervous, alert, quiet, irritated, and excited on a 5-point scale (1 = not at all to 5 = very much). Affect items were drawn from previous literature and selected to capture a broad range of positively and negatively valenced affective states as well as high and low arousal affect [32, 33]. Mean scores for high arousal positive affect (happy, excited, alert; mean = 3.52, SD = 0.51), low arousal positive affect (calm, quiet; mean = 3.52, SD = 0.55), high arousal negative affect (nervous, irritated; mean = 1.60, SD = 0.52), and low arousal negative affect (sad, sleepy; mean = 1.72, SD = 0.50) were used.

Cortisol and DHEAs

Participants collected saliva samples using Salivettes (Sarstedt, Germany). They were instructed to keep the Salivette in their mouth until it was saturated with saliva while completing the time sampling questionnaires. The first sample was taken directly after waking and the second 30 min later. Participants were beeped and asked to take saliva samples five more times over the course of the day (within 15 min of 09:00, 12:00, 15:00, 18:00, and 21:00 h), covering the full waking period. Samples were stored in the lab at –25°C until they were assayed by Clemens Kirschbaum's laboratory at the Technical University of Dresden, Germany, using a commercially available chemiluminescence immunoassay (IBL Hamburg, Germany). For this study, we only used the five beep-prompted saliva samples because momentary solitude information is only available for the beep-prompted measurement points. Out of 50 possible samples per participant, saliva assays are available for an average of 43.5 (87%, SD = 5.8) for cortisol and 42.9 (86%, SD = 6.1) for DHEAs. The different number of cortisol and DHEAs assays resulted from analyzing cortisol first, which in some cases did not leave enough saliva for DHEAs assays. Mean cortisol across persons and days was 6.0 nmol/l (SD = 1.6 nmol/l) and mean DHEAs was 1.2 ng/ml (SD = 1.0 ng/ml). For analyses, raw cortisol and DHEAs values were log transformed due to skewness of their distributions.

Control Variables

Each person's overall solitude was calculated as the percentage of assessments when they reported being alone out of all completed assessments. On average, participants reported being alone 46% (SD = 24%) of the time. Furthermore, gender (coded as 0 = male, 1 = female), education (0 = no college education, 1 = at least some college education), and age were entered as covariates in all models.[1] Models for cortisol and DHEAs further controlled for BMI, recent smoking, recent consumption of caffeine, alcohol and food intake, recent exercise, and recent use of prescribed or over-the-counter medicine or recreational drugs. Time since waking was also included to account for the diurnal rhythm of both hormones.

Statistical Analysis

To account for the hierarchical structure of the data (measurement points nested within study days nested within persons), multilevel models were estimated to test our hypotheses using HLM 6.08 [34]. First, time-varying within-person associations of momentary solitude with high and low arousal positive and negative affect were estimated in separate but similar models. For example, low arousal positive affect was estimated as a function of momentary solitude, age, gender, education, and overall solitude. The momentary solitude slope reflects change in low arousal affect when participants reported being alone as compared to not being alone. We then extended this model to include a cross-level interaction of age on momentary solitude-affect slopes to examine age differences in affective correlates of solitude (momentary solitude × age).

Second, time-varying within-person associations between momentary solitude and cortisol as well as DHEAs were estimated in separate but similar models. For example, cortisol was estimated as a function of momentary solitude, time since waking, recent medication/drug use, consumption of alcohol, food, and caffeine, exercise, and smoking (within-person predictors) and age, gender, education, BMI, and overall solitude (between-person predictors). The slope of momentary solitude estimates differences in cortisol in situations when participants were alone as compared to when they were with someone else. We subsequently added age as a cross-level interaction term to model age differences in momentary solitude-cortisol slopes (momentary solitude × age).

Momentary solitude was centered at the day mean in order to obtain unbiased estimates of within-day and person slopes. BMI, overall solitude, and age were centered at the sample mean. Time since waking was coded in minutes (waking = 0) and entered as an uncentered variable. Momentary controls, gender, and education were also not centered because they were dummy coded. Models were estimated using the full maximum likelihood method. Significant interactions were probed using a computational tool by Preacher et al. [35]. For every significant cross-level interaction (momentary solitude × age), we estimated the region of significance, which delineates the age range in which the respective association of momentary solitude with an affective or biological correlate is significant.

[1] Household size and retirement status were also included as controls in earlier models but were omitted from further analyses as they did not change results.

Results

Means, standard deviations, and intercorrelations of the central study variables and control variables are presented in table 1. Based on person-level averages, cortisol and DHEAs levels were not correlated with affective states. Further, cortisol levels were not correlated with DHEAs levels. Greater age was associated with higher positive affect, lower negative affect, lower DHEAs levels, lower education, higher BMI, more alcohol intake, more exercise, and more medication/drug use. Furthermore, greater age was related to spending a higher amount of time in solitude ($r = 0.20^{**}$). Participants with higher overall solitude showed lower high arousal positive affect, higher cortisol levels, and higher levels of medication/drug use. Women and men did not significantly differ on any of the study variables except DHEAs, which was higher in men.

Associations of Age and Overall Solitude with Mean Affect and Stress Indices

We first inspected main effects of age and overall solitude on average affect and average cortisol and DHEAs (model A in tables 2 and 3). With increasing age, adults reported more high and low arousal positive affect and less high and low arousal negative affect on average. Furthermore, greater age was associated with higher average cortisol and lower average DHEAs levels. Higher overall solitude was associated with lower average high arousal positive affect, higher average cortisol, and higher average DHEAs. We further explored whether associations of overall solitude with average affective states or average HPA axis activity differed by age. However, age did not moderate relationships between overall solitude and average affective states, nor did it moderate relationships between overall solitude and average cortisol and DHEAs levels. Several other covariates were also associated with cortisol and DHEAs levels in the expected direction. Cortisol levels were positively related to food and caffeine intake and negatively related to BMI and alcohol intake. DHEAs levels were positively associated with medication/drug intake and negatively associated with gender and food intake. Furthermore, both cortisol and DHEAs levels decreased throughout the day.

Associations between Momentary Solitude, Affect, and Age

The main purpose of this study was to examine within-person momentary solitude-affect, momentary solitude-cortisol, and momentary solitude-DHEAs associations.

Table 1. Means, standard deviations, and intercorrelations of central study variables and control variables (n = 185)

Variable	Mean (SD)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Age	48.55 (19.19)	0.20**	0.18*	0.32**	−0.27**	−0.40**	0.07	−0.29**	−0.04	−0.23**	0.14*	0.29**	0.16*	−0.03	0.20**	0.09	0.00
2 Overall solitude	0.46 (0.24)		−0.15*	0.09	−0.07	−0.05	0.22**	0.09	0.05	0.02	0.08	0.15*	0.03	−0.10	0.04	0.01	0.05
3 HAPA	3.52 (0.51)			0.20**	−0.29**	−0.41**	−0.08	−0.07	−0.10	−0.12	0.03	−0.12	−0.02	−0.01	0.15*	−0.11	−0.08
4 LAPA	3.52 (0.55)				−0.35**	−0.26**	0.00	−0.06	−0.13	−0.06	0.10	−0.02	−0.05	−0.18*	0.07	−0.05	−0.05
5 HANA	1.60 (0.52)					0.70**	0.07	0.03	0.12	0.07	−0.11	0.03	0.02	−0.03	−0.14	0.02	0.14
6 LANA	1.72 (0.50)						0.01	0.10	0.13	0.02	−0.12	−0.12	0.03	−0.01	−0.19**	0.00	0.16*
7 Cortisol (nmol/l)	5.98 (1.65)							0.04	−0.04	0.03	−0.15*	0.07	0.13	−0.04	0.04	−0.04	0.08
8 DHEAs (ng/ml)	1.23 (1.00)								−0.27**	−0.01	0.06	−0.09	0.12	−0.10	−0.04	−0.08	0.14
9 Gender	0.51 (0.50)									0.01	−0.07	0.11	−0.02	0.10	−0.05	0.10	−0.03
10 Education	0.87 (0.34)										−0.10	0.01	0.11	0.14	0.10	−0.05	−0.05
11 BMI	25.83 (4.61)											0.14	−0.14	0.05	−0.16*	−0.04	−0.10
12 Med/drug intake	0.09 (0.15)												0.11	0.18*	0.05	0.02	−0.05
13 Alcohol intake	0.06 (0.09)													0.02	0.26**	0.10	0.19*
14 Food intake	0.60 (0.15)														0.21**	−0.01	−0.26**
15 Exercise	0.12 (0.13)															−0.09	−0.06
16 Caffeine intake	0.25 (0.20)																0.24**
17 Smoking	0.05 (0.17)																

HAPA = High arousal positive affect; LAPA = low arousal positive affect; HANA = high arousal negative affect; LANA = low arousal negative affect; BMI = body mass index. Gender was coded 0 = men, 1 = women. Education was coded 0 = no college education, 1 = at least some college education. Momentary controls were coded as 0 = participant did not engage in the respective behavior since the last questionnaire, 1 = participant did engage in the respective behavior since the last questionnaire. Time-sampling measures were averaged (person-level means). * $p < 0.05$; ** $p < 0.01$.

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Table 2. Fixed effects estimates for multilevel models predicting affect measures using full maximum likelihood estimation (n = 185)

Variable	Model A coefficient (SE)	Model B coefficient (SE)
High arousal positive affect		
Intercept	3.660** (0.109)	3.659** (0.108)
Gender	–0.042 (0.072)	–0.041 (0.072)
Education	–0.131 (0.110)	–0.131 (0.110)
Overall solitude	–0.336* (0.164)	–0.337* (0.164)
Age	0.004* (0.002)	0.005* (0.002)
Momentary solitude	–0.175** (0.023)	–0.172** (0.022)
Momentary solitude × age		0.003* (0.001)
Deviance	16,610	16,604
ICC	0.38	
Low arousal positive affect		
Intercept	3.570** (0.108)	3.570** (0.108)
Gender	–0.125 (0.078)	–0.125 (0.078)
Education	0.013 (0.110)	0.013 (0.110)
Overall solitude	0.076 (0.170)	0.076 (0.170)
Age	0.009** (0.002)	0.009** (0.002)
Momentary solitude	0.474** (0.035)	0.473** (0.034)
Momentary solitude × age		–0.002 (0.002)
Deviance	20,745	20,743
ICC	0.30	
High arousal negative affect		
Intercept	1.524** (0.111)	1.524** (0.111)
Gender	0.117 (0.074)	0.117 (0.074)
Education	0.019 (0.106)	0.018 (0.106)
Overall solitude	–0.046 (0.138)	–0.045 (0.138)
Age	–0.007** (0.002)	–0.007** (0.002)
Momentary solitude	0.000 (0.020)	–0.001 (0.020)
Momentary solitude × age		–0.002 (0.001)
Deviance	17,553	17,551
ICC	0.37	
Low arousal negative affect		
Intercept	1.762** (0.102)	1.762** (0.101)
Gender	0.116 (0.068)	0.116 (0.068)
Education	–0.117 (0.099)	–0.117 (0.099)
Overall solitude	0.043 (0.131)	0.043 (0.131)
Age	–0.011** (0.002)	–0.011** (0.002)
Momentary solitude	0.128** (0.024)	0.126** (0.023)
Momentary solitude × age		–0.003* (0.001)
Deviance	17,274	17,269
ICC	0.36	

SE = Standard error; ICC = intraclass correlation. Momentary solitude was coded 0 = not alone, 1 = alone. Gender was coded 0 = men, 1 = women. Education was coded 0 = no college education, 1 = at least some college education. Overall solitude is the percentage of assessments a person indicated being alone over the study period. * $p < 0.05$; ** $p < 0.01$.

We first investigated whether momentary solitude was associated with lower concurrent positive affect and higher concurrent negative affect, taking into account both high and low arousal affective states (table 2, model A). In line with our predictions, results indicate that, relative to being with other people, momentary solitude was associated with reduced high arousal positive affect and increased low arousal negative affect. Contrary to our expectations, the relationship between momentary solitude and low arousal positive affect was positive. No significant association emerged between momentary solitude and high arousal negative affect.

Next, we tested the hypothesized moderating effects of age on momentary solitude-affect slopes (table 2, model B). Models showed that age moderated the associations between momentary solitude and high arousal positive affect and between momentary solitude and low arousal negative affect. In line with expectations, greater age was associated with a weaker negative relationship between momentary solitude and high arousal positive affect and also a weaker positive relationship between momentary solitude and low arousal negative affect (fig. 1). Region of significance analysis showed that the relationship between momentary solitude and low arousal negative affect was not significant in older adults aged 72 years and above. Contrary to predictions, age did not emerge as a significant moderator of the association between momentary solitude and low arousal positive affect or between momentary solitude and high arousal negative affect.

To estimate the proportion of explained variance in high arousal positive affect, low arousal positive affect, high arousal negative affect, and low arousal negative affect, we used the pseudo-R^2 approach [36] to determine the proportion of error variance reduction in our models compared to empty models without predictors. Significant reductions in unexplained variance (4% for high arousal positive affect, 7% for low arousal positive affect, 3% for high arousal negative affect, and 7% for low arousal negative affect) were attained with all models. Adding the cross-level interaction between momentary solitude and age to our models reduced unexplained interindividual differences in momentary solitude-affect slopes by 7% for high arousal positive affect and 6% for low arousal negative affect.

Taken together, momentary solitude was associated with reduced high arousal positive affect and increased low arousal negative affect, but also with increased low arousal positive affect. The associations between momentary solitude and concurrent affect were in part moder-

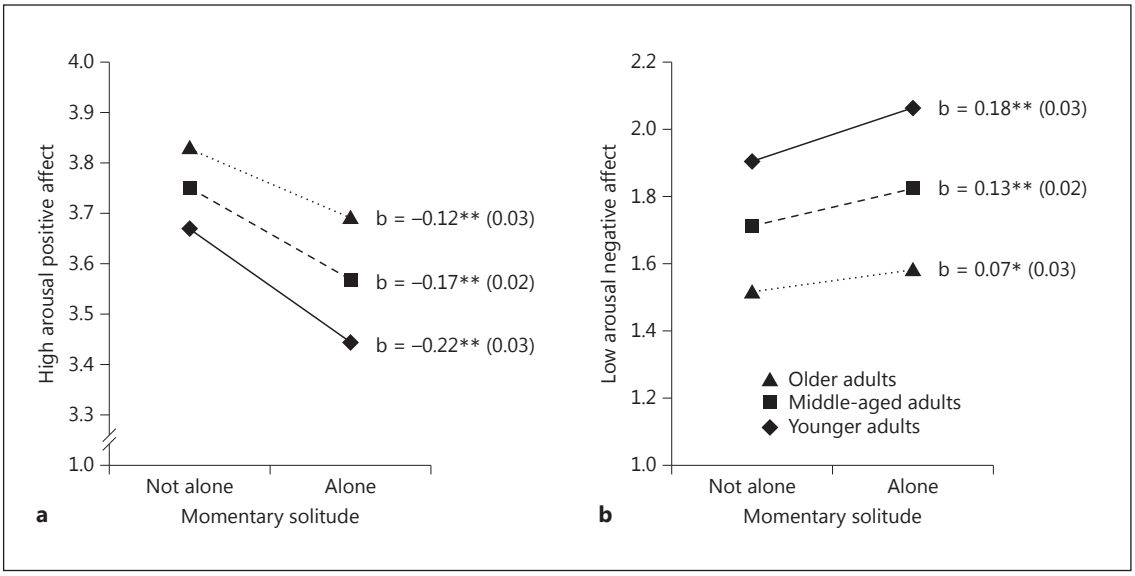

Fig. 1. Illustrations of two-way interactions between momentary solitude and age on high arousal positive affect (**a**) and low arousal negative affect (**b**). For younger, middle, and older age, mean – 1 SD (29 years), mean (49 years), and mean + 1 SD (68 years) are shown for illustrative purposes only. Age was used as a continuous variable in all models. b = Unstandardized coefficient of simple slope. Standard errors of simple slopes are given in parentheses. * $p < 0.05$; ** $p < 0.01$.

ated by age, with greater age being linked to more favorable high and low arousal affect when alone.

Associations between Momentary Solitude, Salivary Cortisol and DHEAs, and Age

Next, we investigated our hypotheses that momentary solitude would be linked to elevated momentary cortisol and DHEAs relative to being with others. In line with expectations, momentary solitude was associated with higher cortisol and DHEAs (table 3, model A).

Subsequently, we tested the hypothesized cross-level interactions involving age and momentary solitude-salivary cortisol and DHEAs associations (table 3, model B). As expected, greater age was associated with a weaker positive association between momentary solitude and cortisol (fig. 2). Specifically, momentary solitude was only associated with higher cortisol in adults aged 20–51 years, as indicated by region of significance analyses. Contrary to predictions, there was no significant cross-level interaction of age on momentary solitude-DHEAs associations.

Finally, we evaluated model fit for models containing salivary hormonal measures. All models significantly reduced unexplained variance (2% for cortisol, 14% for DHEAs) in comparison to models that only included control variables.[2] Inclusion of the cross-level interaction between momentary solitude and age reduced unexplained interindividual differences in momentary solitude-cortisol slopes by 17%.

Taken together, momentary solitude was associated with increased cortisol and DHEAs compared to being with others. Greater age was associated with a weaker positive association between momentary solitude and cortisol levels.

Discussion

The purpose of this study was to paint a more nuanced picture of both positive and negative correlates of momentary solitude (defined as the objective condition of being alone at a certain point in time) while controlling for the overall amount of time spent alone (overall solitude) along with a number of well-established covariates. Analyses of repeated daily life assessments from a life span sample demonstrate that momentary solitude was

[2] Models were compared with models only containing control variables instead of empty models as time since waking explained a large amount of variance, which can be attributed to the diurnal rhythm of both hormones.

Table 3. Fixed effects estimates for multilevel models predicting salivary hormonal measures using full maximum likelihood estimation (n = 185)

Variable	Model A coefficient (SE)	Model B coefficient (SE)
Cortisol		
Intercept	1.084** (0.030)	1.083** (0.030)
Time	–0.001** (0.000)	–0.001** (0.000)
Medication/drug intake	0.018 (0.010)	0.019 (0.010)
Alcohol intake	–0.028* (0.014)	–0.027* (0.014)
Food intake	0.021** (0.006)	0.021** (0.006)
Exercise	–0.001 (0.010)	–0.001 (0.010)
Caffeine intake	0.015* (0.007)	0.015* (0.007)
Nicotine intake	–0.024 (0.022)	–0.023 (0.022)
Gender	–0.024 (0.017)	–0.024 (0.017)
Education	–0.001 (0.030)	–0.000 (0.030)
Body mass index	–0.006** (0.002)	–0.006** (0.002)
Overall solitude	0.115** (0.037)	0.115** (0.038)
Age	0.001* (0.000)	0.001** (0.000)
Momentary solitude	0.017* (0.007)	0.016* (0.007)
Momentary solitude × age		–0.001* (0.000)
Deviance	–2,513	–2,519
ICC	0.13	
DHEAs		
Intercept	0.101 (0.064)	0.101 (0.064)
Time	–0.000** (0.000)	–0.000** (0.000)
Medication/drug intake	0.036** (0.010)	0.036** (0.010)
Alcohol intake	0.006 (0.011)	0.007 (0.011)
Food intake	–0.027** (0.006)	–0.027** (0.006)
Exercise	0.003 (0.008)	0.003 (0.008)
Caffeine intake	–0.004 (0.007)	–0.004 (0.007)
Nicotine intake	0.019 (0.020)	0.019 (0.020)
Gender	–0.205** (0.031)	–0.205** (0.031)
Education	0.015 (0.065)	0.015 (0.065)
Body mass index	0.004 (0.003)	0.004 (0.003)
Overall solitude	0.139* (0.068)	0.139* (0.068)
Age	–0.006** (0.001)	–0.006** (0.001)
Momentary solitude	0.023** (0.006)	0.023** (0.006)
Momentary solitude × age		–0.000 (0.000)
Deviance	–2,871	–2,871
ICC	0.63	

SE = Standard error; ICC = intraclass correlation; DHEAs = dehydroepiandrosterone sulfate. Momentary solitude was coded 0 = not alone, 1 = alone. Gender was coded 0 = men, 1 = women. Education was coded 0 = no college education, 1 = at least some college education. Momentary controls were coded as 0 = participant did not engage in the respective behavior since the last questionnaire, 1 = participant did engage in the respective behavior since the last questionnaire. Overall solitude is the percentage of assessments a person indicated being alone over the study period. All cortisol level units are $\log_{10}$ nmol/l; all DHEAs level units are $\log_{10}$ ng/ml. * $p < 0.05$; ** $p < 0.01$.

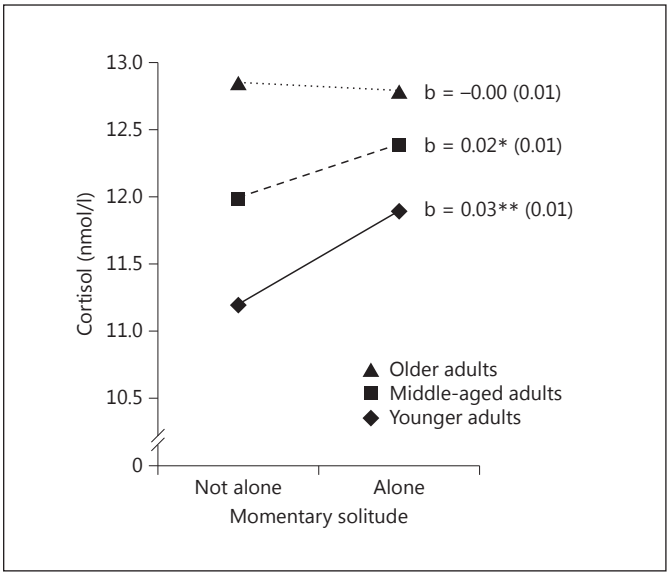

Fig. 2. Illustration of two-way interaction between momentary solitude and age on cortisol. For younger, middle, and older age, mean – 1 SD (29 years), mean (49 years), and mean + 1 SD (68 years) are shown for illustrative purposes only. Age was used as a continuous variable in all models. Log-transformed cortisol was transformed back into nmol/l. b = Unstandardized coefficient of simple slope. Standard errors of simple slopes are given in parentheses. * $p < 0.05$; ** $p < 0.01$.

associated with reduced high arousal positive affect and increased low arousal negative affect. However, momentary solitude was also associated with increased low arousal positive affect, pointing to potential beneficial effects and underscoring the importance of distinguishing between high and low arousal positive and negative affective states. Age moderated these associations such that greater age was associated with more high arousal positive affect and less low arousal negative affect when alone. In line with expectations, momentary solitude was associated with increased cortisol and DHEAs. Of note, older age was associated with less pronounced momentary solitude-cortisol slopes. No age interaction emerged for the momentary solitude-DHEAs association.

Solitude, Affect, and Age

A central goal of this study was to address within-person associations between momentary solitude and affect. Findings are in line with previous studies reporting lower positive and higher negative affect in adolescents, college students, and older adults when alone [4, 5, 37]. Interestingly, findings were specific to high arousal positive affect

and low arousal negative affect, whereas expectations regarding associations between momentary solitude and low arousal positive affect and high arousal negative affect were not confirmed. In fact, contrary to the hypothesized negative relationship, momentary solitude was associated with increased low arousal positive affect. Furthermore, the expected positive association between momentary solitude and high arousal negative affect did not reach statistical significance. These results are interesting from a conceptual and a methodological perspective. Conceptually, we take these findings as initial evidence that being alone is not necessarily a negative experience. Instead, sometimes in solitude we may be liberated from social pressures and expectations and consequently free to engage in desired activities and thoughts [14]. Our findings support the idea that momentary solitude might promote low arousal positive states like calmness and relaxation, which may facilitate self-reflection, creative thinking, and emotional renewal [3, 14]. This underscores the importance of questioning and revisiting the negative view of time alone and emphasizes that momentary solitude should not be equated with overall solitude or loneliness.

Our findings are also interesting methodologically. Most previous research examining momentary solitude-affect associations has been based on bipolar scales with two opposing affective states (e.g. happy/sad; [5]), while we employed unipolar scales to measure affect. One exception is a time sampling study by Matias et al. [13] using unipolar affect ratings, which found that anxiety (a high arousal negative affective state) was unrelated to solitude in female college students. This corresponds with our finding of no statistically significant relationship between momentary solitude and high arousal negative affect. Momentary solitude was simultaneously associated with increased low arousal positive affect and increased low arousal negative affect in our study. One explanation might be that low arousal affect is more salient during solitude as attention is directed towards internal states [10]. Moving forward, it thus seems important to paint a more differentiated picture of momentary solitude-affect associations by taking distinctions between high and low arousal affective states into account and by using unipolar affect ratings. This notion also dovetails with previous research indicating that older adults are more likely to prefer low arousal affective states to high arousal affective states [38].

A main goal of this study was to test age differences in the experience of momentary solitude. By covering a relatively large age range (20–81 years), our sample was uniquely suited to examine whether affective and biological correlates of momentary solitude differed by age. In line with previous literature, greater age was linked with spending more time alone in our sample [1]. As predicted, age moderated the associations between momentary solitude and both decreased high arousal positive affect and increased low arousal negative affect such that these links were less pronounced with greater age. This is consistent with previous evidence from younger samples, which showed that negative associations between momentary solitude and the bipolar measures of happy/sad, sociable/lonely, alert/drowsy, and active/passive were stronger in adolescents as compared to adults [3]. Results are also in line with conceptual notions derived from socioemotional selectivity theory [39], which posits that older adults, who due to their advanced age have a more limited future time perspective than young adults, prioritize emotionally meaningful goals, which is accompanied by an optimization of current affect and better everyday emotion regulation. Our findings are also in accordance with the sentiment that, on the one hand, older adults might be more competent in regulating their affect during momentary solitude. On the other hand, older adults' higher tendency to focus on the positive and to savor current experiences might result in their appraising momentary solitude less negatively, thereby weakening or preempting any potential negative affective responses. Of note, associations between momentary solitude and low arousal positive affect and high arousal negative affect were not moderated by age. Future research needs to look into additional factors that might allow older adults to reap the potential benefits of ubiquitous solitude experiences, including person-specific factors (e.g. generally high feelings of social integration and high-quality relationships with close others) and situation-specific factors (e.g. voluntarily seeking out alone time) [2, 40, 41].

Solitude, HPA Axis Activity, and Age

Beyond associations with affect, we investigated associations of momentary solitude with two HPA axis activity markers – cortisol and DHEAs. We expected that, compared to being with others, momentary solitude would be linked to higher cortisol and DHEAs levels. Consistent with previous studies [13, 18, 19], cortisol levels were higher when alone than when with others. In addition, our findings provide first evidence that momentary solitude is further related to higher DHEAs levels. Hence, ramifications of momentary solitude are not only visible in self-reported affective states but also in biological stress indices; HPA axis activity seems to be higher

when individuals are alone than when other people are present. However, the health implications of these findings might not be as negative as has previously been suggested based on findings of associations between momentary solitude and cortisol [13]. DHEAs has been associated with a variety of beneficial effects including promotion of growth and survival of neurons, inhibition of inflammation, enhancement of immune function, and protection against glucocorticoid-induced neurotoxic effects [23]. We thus speculate that DHEAs could buffer potential negative health ramifications of increased cortisol during momentary solitude.

Confirming our expectations, the association between momentary solitude and cortisol was moderated by age. Region of significance analyses suggest that adults aged 20–51 years showed higher cortisol when alone than when with others, while cortisol levels of adults aged 52 years and above were not associated with momentary solitude. Findings are remarkable in light of the heightened physiological vulnerability of older adults in that older adults seem to be able to avert negative ramifications of solitude with regard to increased cortisol [24, 29]. Future research needs to look at underlying mechanisms such as the increased use of passive emotion regulation strategies and a higher tendency to focus on the positive among older adults, which might lead to more positive solitude appraisals and in turn prevent physiological reactivity [29, 39]. Alternatively, the lack of a physiological response to momentary solitude in older adults might also indicate a dysfunction of this stress system [29]. The association between momentary solitude and DHEAs was not moderated by age. A possible explanation for not detecting a significant interaction could be the limited variability in DHEAs at the measurement occasion level (32%, compared to 87% for cortisol).

Associations of Age and Overall Solitude with Mean Affect and Stress Indices

Main effects of age on affect and HPA axis activity are in accordance with previous research showing that greater age is positively associated with affective well-being [16, 17], but also linked with higher cortisol and lower DHEAs levels on average [24, 26, 28]. Moreover, the current study paints a more differentiated picture regarding the relationship between the overall amount of time spent alone (overall solitude) and affect as well as biological correlates. Results indicate that higher overall solitude is linked to lower average high arousal positive affect but unrelated to low arousal positive affect and both high and low arousal negative affect. Greater overall solitude was further related to higher average cortisol and DHEAs levels. This concurs with the findings of Grant et al. [9], who showed that objective social isolation, as measured by living alone and/or having little or no contact with relatives and friends, was linked to higher cortisol secretion in healthy middle-aged adults. In contrast to momentary solitude, higher overall solitude indeed seems to have very clear negative connotations, which is in line with the extant literature on negative effects of social isolation on mental and physical health [8, 12]. Consequently, as no age differences emerged in associations of overall solitude with mean affect and mean HPA axis activity, the higher amount of time spent alone in old age might be accompanied by adverse health ramifications.

Strengths, Limitations, and Future Directions

The present study is unique in that it uses a time sampling design to assess relationships between momentary solitude, affect, and HPA axis activity in an everyday life context, enabling us to look at both within- and between-person associations, while maximizing ecological validity. Another strength is the broad age span (20–81 years), with relatively equal numbers of young, middle-aged, and older adults, enabling an assessment of age differences in the experience of momentary solitude. Furthermore, we incorporated both subjective and physiological measures to get a comprehensive picture of momentary solitude experiences. Nevertheless, our findings have to be interpreted in light of the following limitations. Although the time sampling design offers several advantages, the present data are correlational, and hence findings do not allow causal inferences. Our cross-sectional results also only hint at but cannot prove aging processes. In addition, we only used two items for each affect dimension, except for high arousal positive affect, to reduce participant burden. Results might therefore be influenced by selecting specific affect items. Findings need to be replicated using a larger number of items to strengthen reliability and validity of affect dimensions. We also do not know if participants had control over how much time they spent alone or if they actively sought out time alone. This might be an important factor to consider because cross-sectional research has shown that voluntarily spending time alone is associated with lower loneliness and higher well-being than involuntary solitude [40]. Age differences in correlates of momentary solitude experiences could thus be explained by older adults spending more voluntary time in solitude or having a higher preference for solitude [2]. Furthermore, despite an effort to recruit participants of different cultural heritages and social backgrounds to en-

sure a broad representation of older adults in the Atlanta metropolitan area, our sample is relatively select in terms of health and education, in part due to exclusion criteria for analyzing HPA axis markers. Results pertaining to correlates of momentary solitude in older adults are therefore limited to relatively healthy and high-educated individuals. Lower socioeconomic status, which is highly correlated with education, has been associated with poorer physical and mental health. Negative socioeconomic status health links may be partly explained by a lack of resources to cope with everyday challenges (e.g. perceived control, social support, and social integration; [42]) among individuals with low socioeconomic status. It is possible that these resources are a sine qua non for positive solitude experiences. Moreover, individuals with poor health might have limited mobility, which restricts their ability to leave the house and to engage in social interactions. Thus, poorer health might be associated with more involuntary time in solitude and, in turn, with less favorable correlates of momentary solitude. Future studies are needed to test whether momentary solitude is also associated with more favorable experiences with greater age in less healthy and educated samples. It might be useful, furthermore, to compare solitude with different types of social interactions – for instance, by taking both the quality of the social interaction and the closeness with one's social interaction partner into account [15]. Finally, future work might extend this study by investigating relationships between solitude and markers of autonomic nervous system activity, such as heart rate or salivary α-amylase, to more thoroughly understand biological correlates of solitude along both of the body's main stress axes.

Conclusions

Spending time alone has a negative reputation, in part due to compelling evidence of the negative effects of objective social isolation and perceived loneliness on physical and mental health [6, 8]. However, equating the objective condition of being alone (momentary solitude) with social isolation or with subjective perceptions of loneliness risks neglecting any potential benefits of time spent alone. The current study focused on momentary solitude and aimed to paint a more nuanced picture of how individuals across the adult life span feel when they are alone and how this is linked to key HPA axis activity markers. Findings regarding affective correlates of momentary solitude demonstrate that time alone has positive as well as negative connotations. On the one hand, momentary solitude (relative to being with other people) is associated with reduced high arousal positive affect and increased low arousal negative affect. On the other hand, momentary solitude is also associated with increased low arousal positive affect. Concerning biological correlates of momentary solitude, HPA axis activity was increased when participants reported being alone relative to when with others. Particularly relevant to aging research, these associations were not the same across the adult life span. Greater age was associated with reporting more favorable affect when alone and adults aged 52 and above did not show increased cortisol during momentary solitude in contrast to their younger counterparts. Given that time alone is a ubiquitous experience that increases with age [1], these findings not only contribute to a better understanding of the experience of momentary solitude and age-related differences therein, but also point to potential benefits of momentary solitude. These benefits need to be better understood and have the potential to help older adults improve their emotional well-being and reduce their stress in everyday life. Future research needs to address specific resources and psychological mechanisms (such as increased use of passive emotion regulation skills, focusing on optimizing current affective experiences, and having emotionally meaningful and satisfactory social contacts [29, 39, 41]) that might help older adults capitalize on the benefits of momentary solitude and reduce the disadvantages of spending a high amount of time alone.

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